

High Altitude Recoverable Drop Vehicle

Abstract

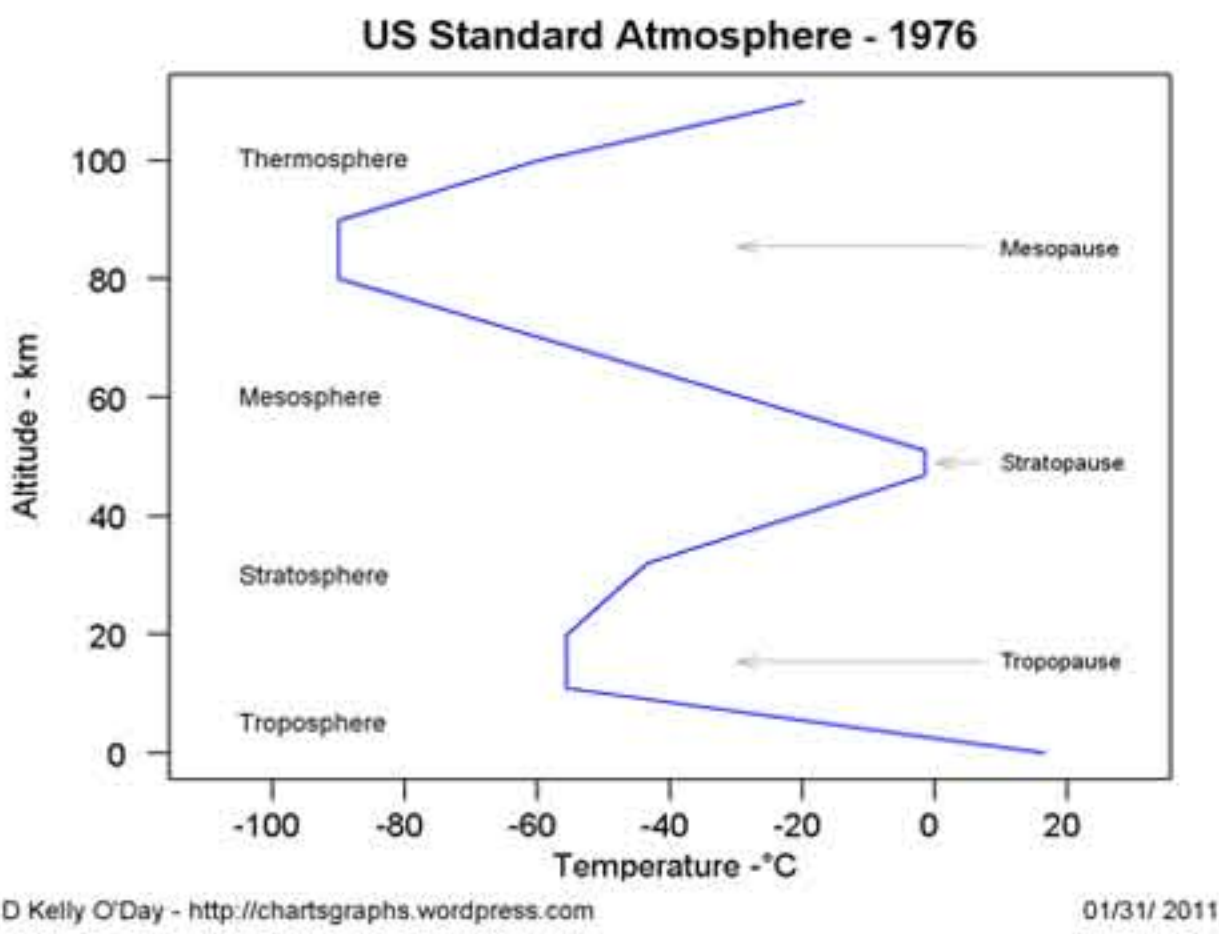
High altitude balloons offer researchers a low cost means to access a unique environment. Balloons can travel higher than most aircraft and take payloads as close to space as most projects will get to go. The problem with using balloons for research projects, especially in Alaska, is recovering the payload and data after the flight. Traditionally the payload falls back to earth with an unguided parachute while a GPS reports it's landing location. The research team then has to go to the payload to recover it. This can be difficult if it lands in a remote location. By using an unmanned glider, the aircraft and payload will return to the launch point, or any location within it's glide range. This prevents having to spend time and resources recovering the downed payload. Since unmanned aircraft are now easy to operate and are becoming more affordable, it would not increase the cost of the project much and reduces the risk of losing expensive payloads.

The goal of this project is to design, build and test a unmanned glider or Unmanned Aerial System (UAS, also known as a drone or UAV) that is carried to high altitude with a balloon and release it before the balloon bursts. The UAS will use GPS and IMU navigation to pilot itself to a defined location, presumably back to where it took off from. Applications include carrying payloads like cameras, atmospheric sensors and aerosol samplers, to delivering medicine and vaccines to remote locations. Flight status and mission parameters can be viewed and changed in real time by using a radio and ground station with tracking antenna.

Challenges

Operating at high altitude poses several design challenges. Air density and temperature generally decrease with elevation. This makes designing an aircraft that can operate in such a large environmental range even more difficult.

The standard temperature at 12 km (40,000 ft) is -56 degrees C (-70 degrees F). If not heated, this temperature would cause problems with the batteries and mechanical components, jeopardizing the aircraft. The fuselage is made of polystyrene foam which will insulate the components. Heating the payload area with batteries increases weight but is easy to regulate. Another option is to use a chemical heat source. Heat loss can be tested in a cold chamber before sending a plane up. Data from other balloon flights can be correlated with altitude and temperature allowing for accurate battery sizing.



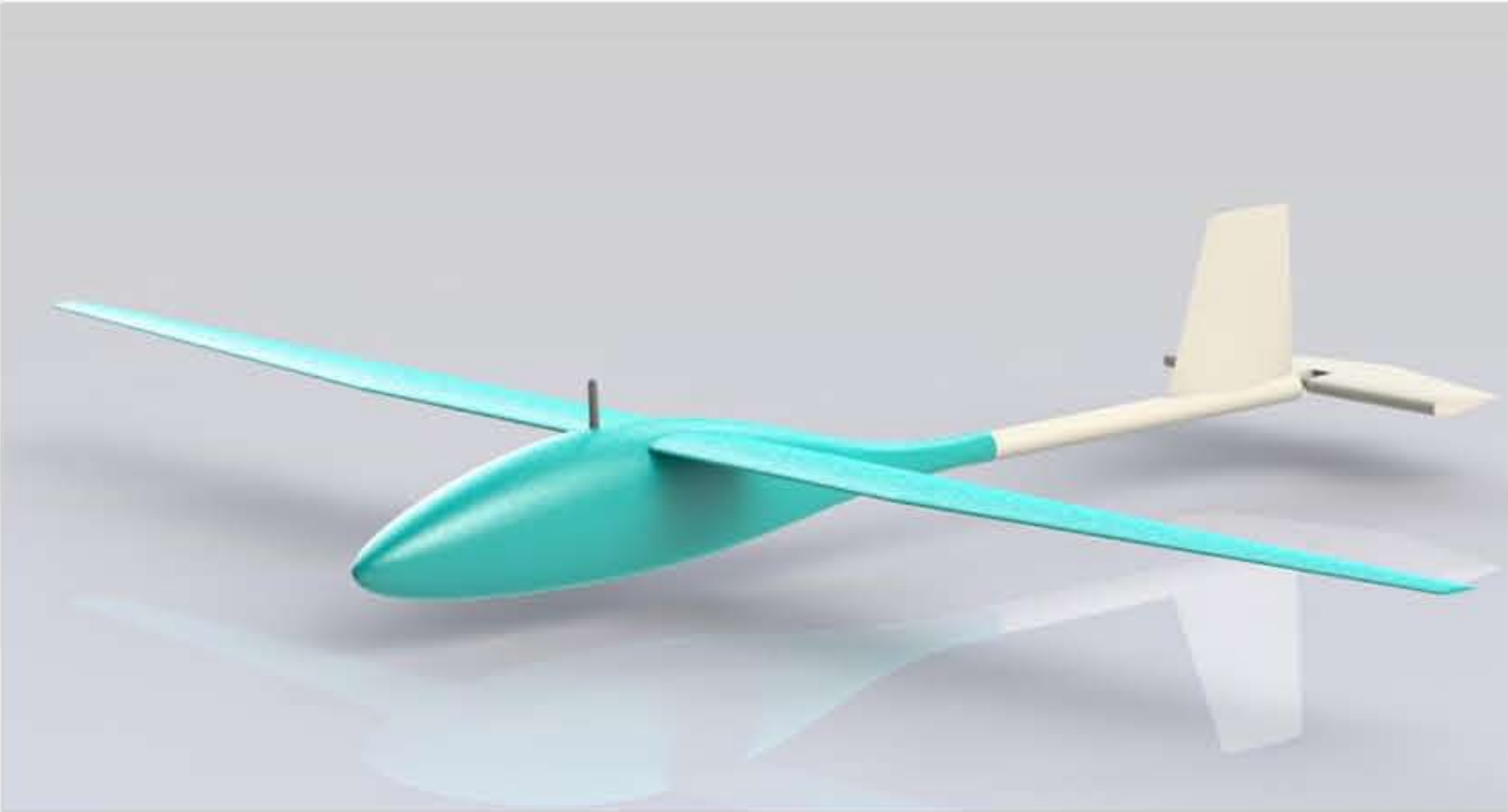
The autopilot on the aircraft is an ArduPilot Mega 2.5, an open source Arduino controller. It uses PID control loops that are aircraft specific and are affected by wind and air density. As the aircraft descends, it will experience higher density air and have to adapt for changes in wind. The dynamic pressure depends on both air density and speed. This should simplify the problem with control loops since the glider will just fly faster at high altitudes. Since the UAS is unpowered, it must be dropped from a balloon or another aircraft each flight during testing. This increases the required time to make the system stable.

Prototype Design

Two prototype designs were considered for the project. Both have a target altitude of 12 km. The first is similar to a conventional glider with a high aspect ratio wing that allows it to fly long distances and stay aloft longer. This type of aircraft is harder to build because it requires composites like Kevlar and carbon fiber to make the thin wings strong enough. It is also susceptible to damage in high winds and wind shears. One of the potential applications for the the HARDV is volcano ash cloud sampling. Depending on how close the sample is to the volcano, the ash cloud could create a situation that would be difficult to predict and operate with this type of wing. A larger glider would be hard to tow or lift repeatedly during autopilot tuning. Conversely, it also flies longer, providing a larger data sample.

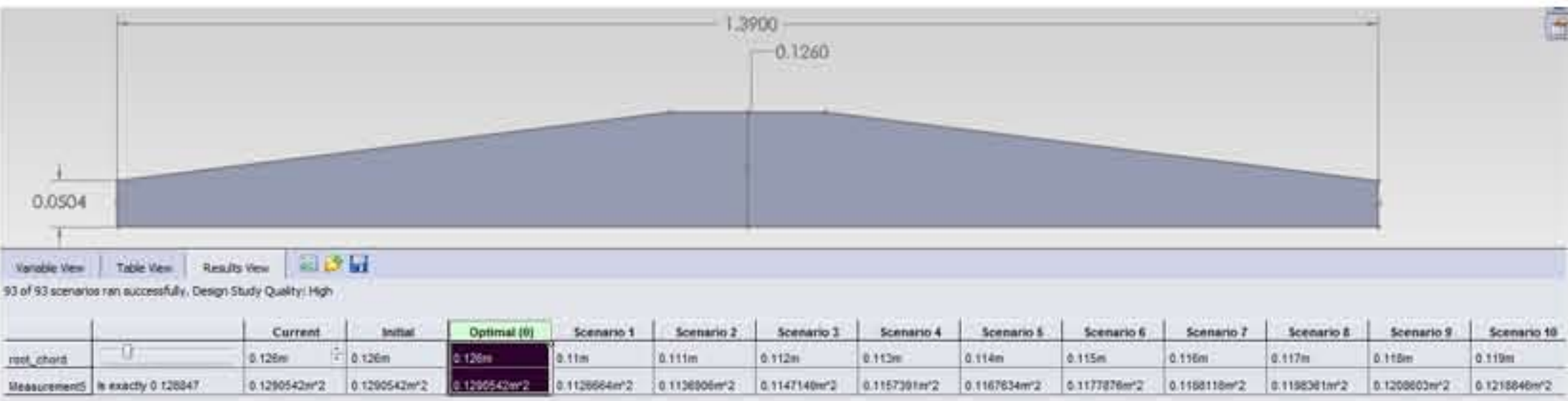
The second prototype design has a short, stubby, low aspect ratio wing. At the cost of range and endurance, this configuration would fly much faster and be able to punch through any hazardous conditions. It would be easier to build and could even be 3D printed in sections that would lock together. To reduce issues with the thermal properties of layered plastic at extreme temperatures, it could also be strengthened with a composite material. Testing a small aircraft would be easier because it could be lifted and dropped by a multi-rotor UAS, allowing for more tests than if a balloon or tow aircraft were used.

The first design was selected with the understanding it would probably end up being something in between the two models. Aircraft design is an iterative process where things like total aircraft weight must be known (estimated) before the rest of the design can be done. However, as the design changes, so do higher dependencies like weight, wingspan, and the airfoil. It is difficult to not get caught in a loop that prevents any real work from getting done. A good approach is to make estimations, build and test a prototype, then see what needs to be changed. At this small scale it is easier to fly full scale prototypes rather than spend the time and money on computer simulations and wind tunnel tests.



CAD model of UAS prototype

After the aircraft parameters were calculated, a 3D model was drawn. The model is later used in the build process but is also used to find weight and balance and for component optimization. Wing size and geometry can quickly be solved for by inputting the desired wing area and aspect ratio (or any combination of variables). This allows for rapid prototyping of wings, the most time consuming part of the aircraft to build.

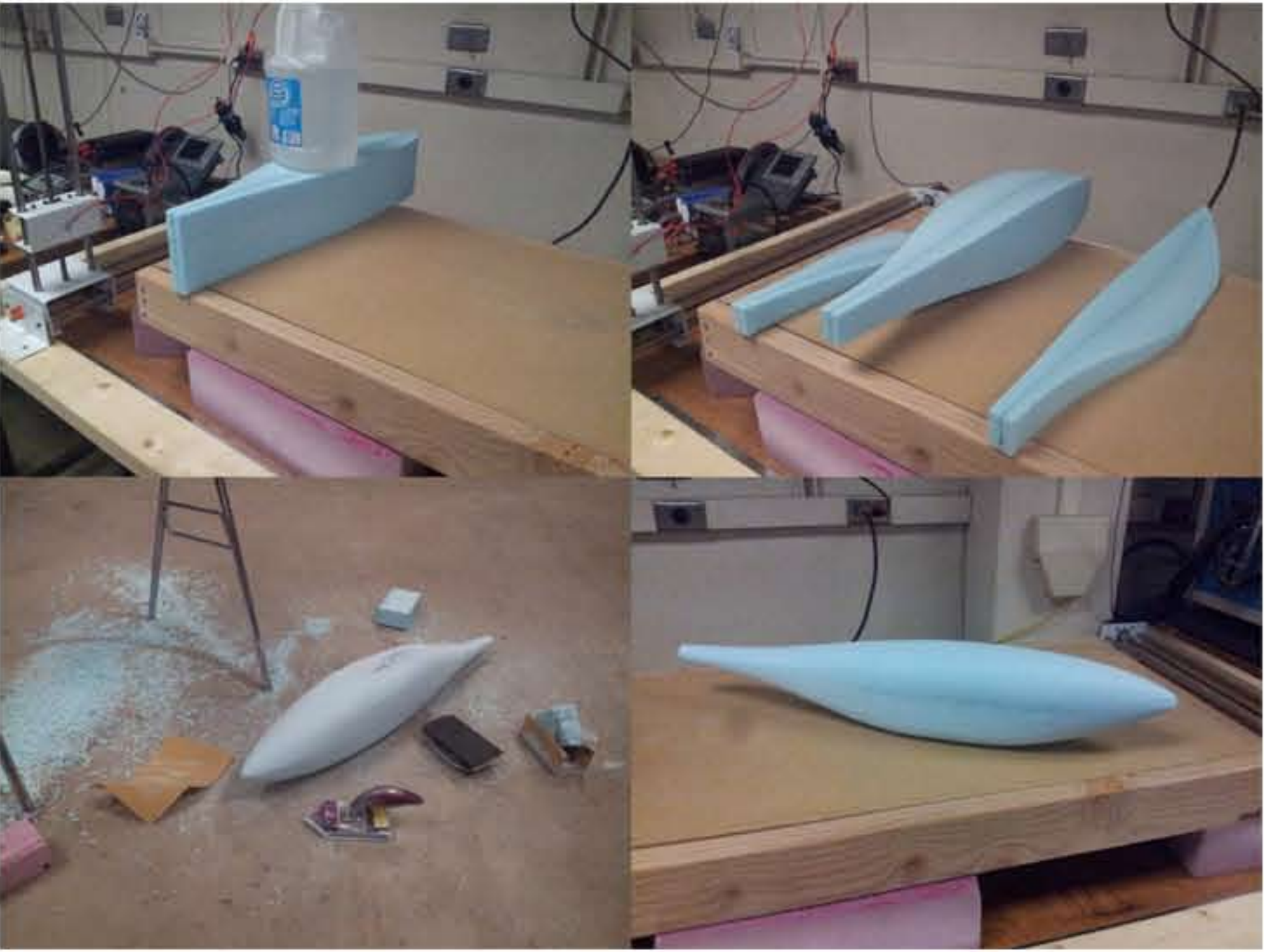


Wing geometry optimization

Design and Construction

Construction

2D profiles are taken from the CAD model and used to drive a CNC hotwire cutter. The CNC cutter has two parallel X, Y axis. A thin wire runs between the two axis and electrical current flows through the wire, heating it past the melting point of foam. The axis are computer controlled and can move independently of each other allowing for tapered cuts. Three inch blocks of foam are positioned inside the cutting area of the machine and are cut to whatever profile the computer sends it. By making a cut of the fuselage side profile, then rotating it 90 degrees to cut the top profile, a rough block of the fuselage can be made. From there, a regular knife and sanding block are used to make the curves between the flat surfaces of the cuts. This part could be avoided by using a four or five axis CNC mill which would quickly produce identical aircraft components with complex surfaces. For prototyping, the hot wire works very well.



CNC hotwire foam cutter with prototype fuselage in various build stages

Composites

Since the foam alone is weak, a composite material is used to add rigidity and strength. Carbon fiber will be used for most of the aircraft, covering the fuselage, tail and wings. Because carbon fiber is brittle after it cures, Kevlar will be used to make fabric hinges for the control surfaces. Kevlar is still strong and light but does not shatter like carbon fiber. It can be bent, breaking the epoxy bond without ripping the fabric.

Since the wing cores are cut from foam, a negative mold of the wing is left over after the core is removed. The core is cut at the leading edge so that it has a top and bottom half that sandwich the core. When the hotwire cuts the foam, it removes roughly 1.2 mm of material known as kerf. The kerf has to be filled to ensure good mold compression. The carbon fiber is .33 mm per layer and is covered with a thin release film to prevent it from sticking to the mold when it is removed. The layup process begins when the epoxy and carbon fabric are placed in the molds. All the control surfaces, channels, and attachment points are cut into the foam before the layup so no cuts that would weaken the airframe have to be made later. The carbon fabric is rolled out and cut to fit the mold then placed on a sheet of release material. Epoxy resin and hardener are mixed by weight and spread on the fabric. When the fabric is ready to go in the mold, the release film is cut slightly larger than the carbon fiber. This gives the carbon fiber a wrinkle free backing and keeps the fabric from distorting when it is pulled off the table, making a better finish on the final part.

When all the pieces are laid up in the mold, the foam core is placed inside and the top mold is fitted over it. An electric blanket is wrapped around the mold before weights are placed on top to make the final part stronger. The layup process is quite time consuming and varies depending on the shape of the part. A large part of the research time was spent developing a method for making good composite parts.



Carbon fiber wing test section Composite layup area

Results

-For a separate project, a six foot carbon fiber wing was made with these methods. It weighs 1210g (2.6 lbs) and is incredibly strong. By using absorbent material in future lay up processes, excess epoxy will be removed making the part even lighter.
 -The electronics and radios are configured and tested. They are fitted in the payload bay.
 -To save time on the prototype, a tail assembly from a RQ-11 Raven UAS is being used. A similar tail configuration will be used on the final aircraft.
 -The composite lay up method is the current limiting factor for high aspect ratio wings. More experience with composites and CNC machines will increase the aircraft quality, range, and endurance.
 -Aircrafts and balloons can be scaled to fit different payloads.



HARDV fuselage with Raven UAS tail

Impact

Having an unmanned aircraft quickly return samples from the atmosphere means better data collection in less time. By using a balloon for lift, the HARDV UAS can take ever shrinking payloads higher and higher, allowing longer flights and larger coverage areas. There are many applications for the HARDV glider but the tasks that powered UAS cannot do well are especially interesting. Collecting ash cloud samples from volcanos will damage the motors of powered aircraft. However, gliders can pass through the ash without problem, and by not having a motor, large battery, or engine, autonomous gliders are cheaper to build. Small disposable drones are already being dropped by larger unmanned aircraft during storms, but the flight duration of any powered aircraft is limited by the fuel it carries. Disposable HARDV UAS could deliver aid supplies to places where keeping vaccines cold is a problem. Sensitive medicine would be kept cold in the high atmosphere and delivery would be fast and accurate. During natural disasters, numbers of large unmanned gliders could be dropped from a cargo plane or loiter for days in airships. Search and rescue drones or scientific payloads would be available at a moments notice. Many people are understandably concerned about the future role of unmanned vehicles, but working on positive roles will help to reshape their image.

References

Shevell, Richard Shepherd. Fundamentals of Flight. Englewood Cliffs, NJ: Prentice-Hall, 1983. Print.